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Yanase et al.

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(54) **SEMICONDUCTOR DEVICE AND METHOD FOR MANUFACTURING SEMICONDUCTOR DEVICE**

(2013.01); *H01L 21/0485* (2013.01); *H01L 29/402* (2013.01); *H01L 21/046* (2013.01)

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USPC 257/77, 76, 328, 329, 7, 93, 334, 427, 257/444, 262, 368-401, E29.255-E29.313, 257/E29.315-E29.316; 438/105, 212, 268, 438/931

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See application file for complete search history.

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H01L 31/0312 (2006.01)

(Continued)

(57) **ABSTRACT**

According to one embodiment, a semiconductor device includes a SiC layer of a first conductivity type, a SiC region of a second conductivity type, and a conductive layer of the second conductivity type. The SiC layer of the first conductivity type has a hexagonal crystal structure. The SiC region of the second conductivity type is formed in a surface of the SiC layer. The conductive layer of the second conductivity type is provided on the SiC region and is in contact with a portion of the SiC region including SiC of a cubic crystal structure.

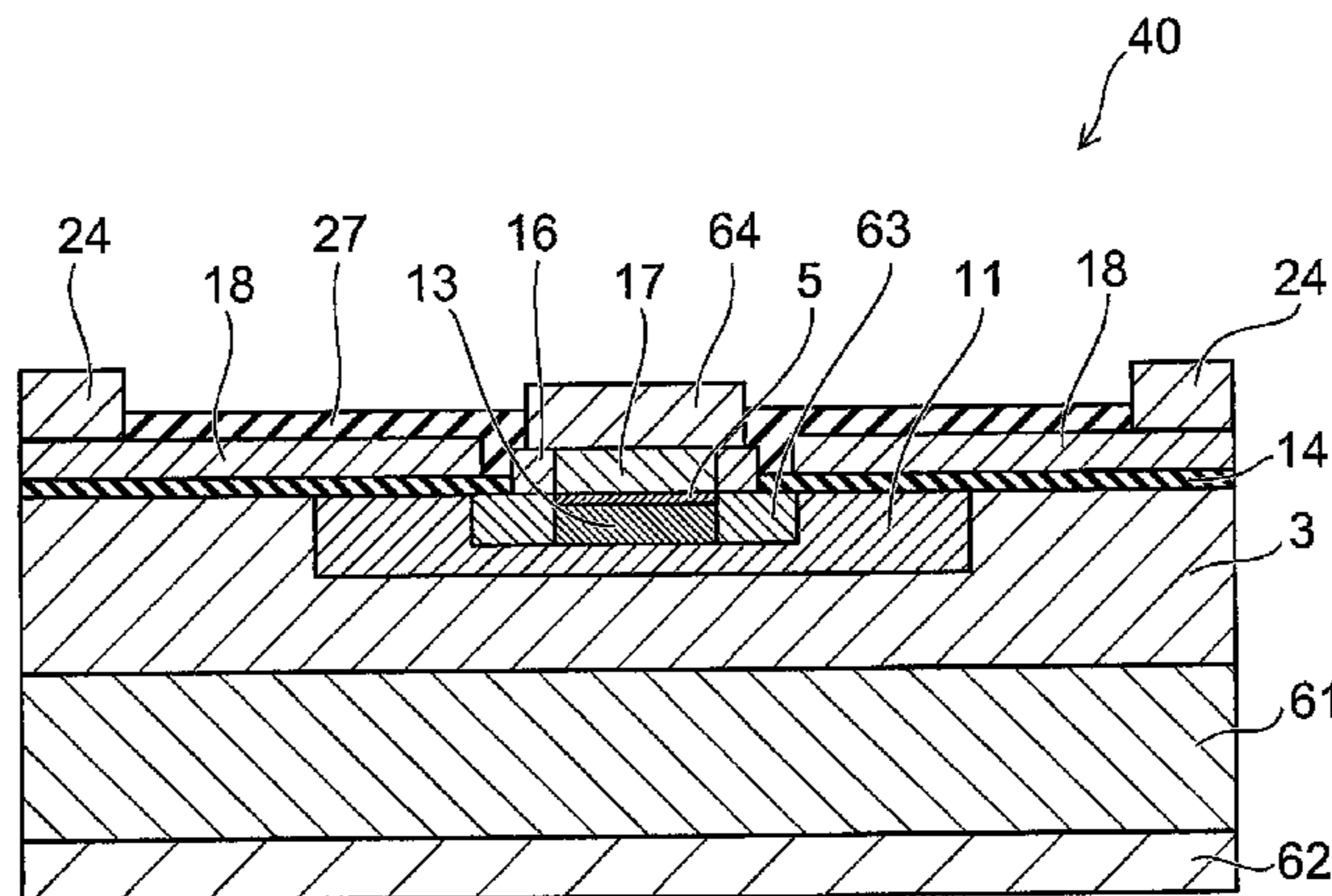
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CPC *H01L 29/04* (2013.01); *H01L 29/1608*

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H01L 29/7802 (2013.01); *H01L 29/66068*

7 Claims, 9 Drawing Sheets



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H01L 29/78 (2006.01)
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H01L 21/04 (2006.01)
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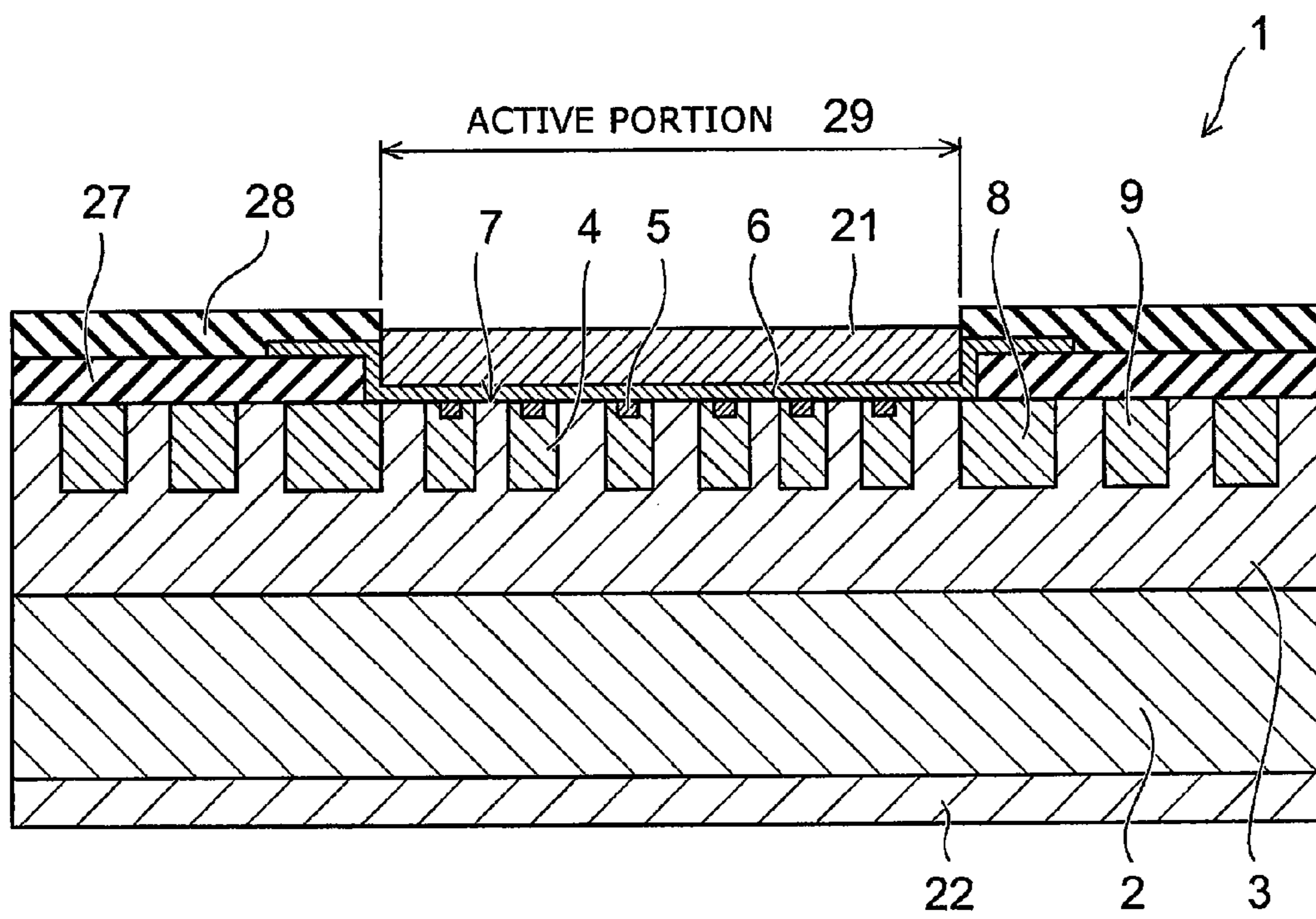


FIG. 1

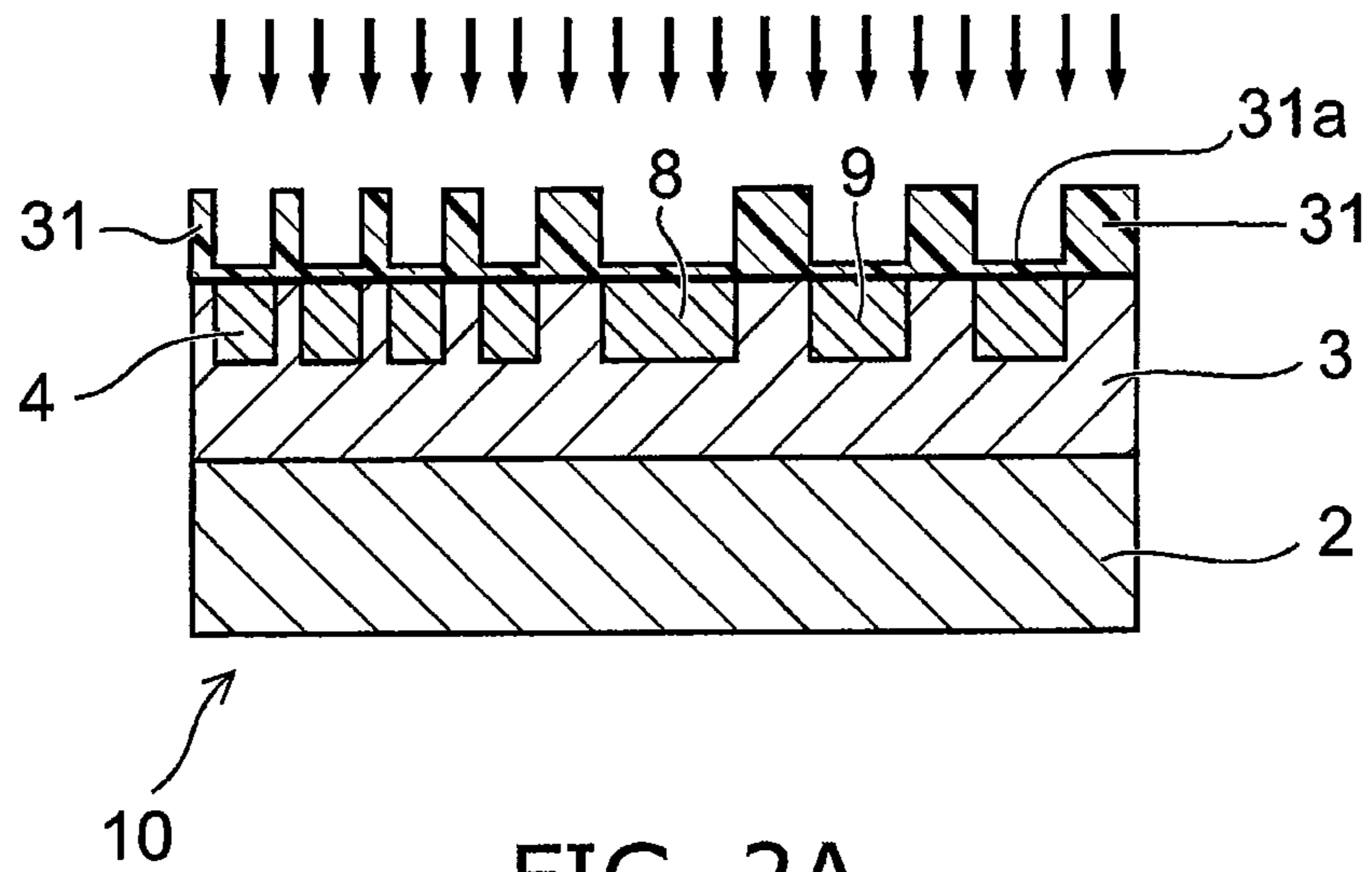


FIG. 2A

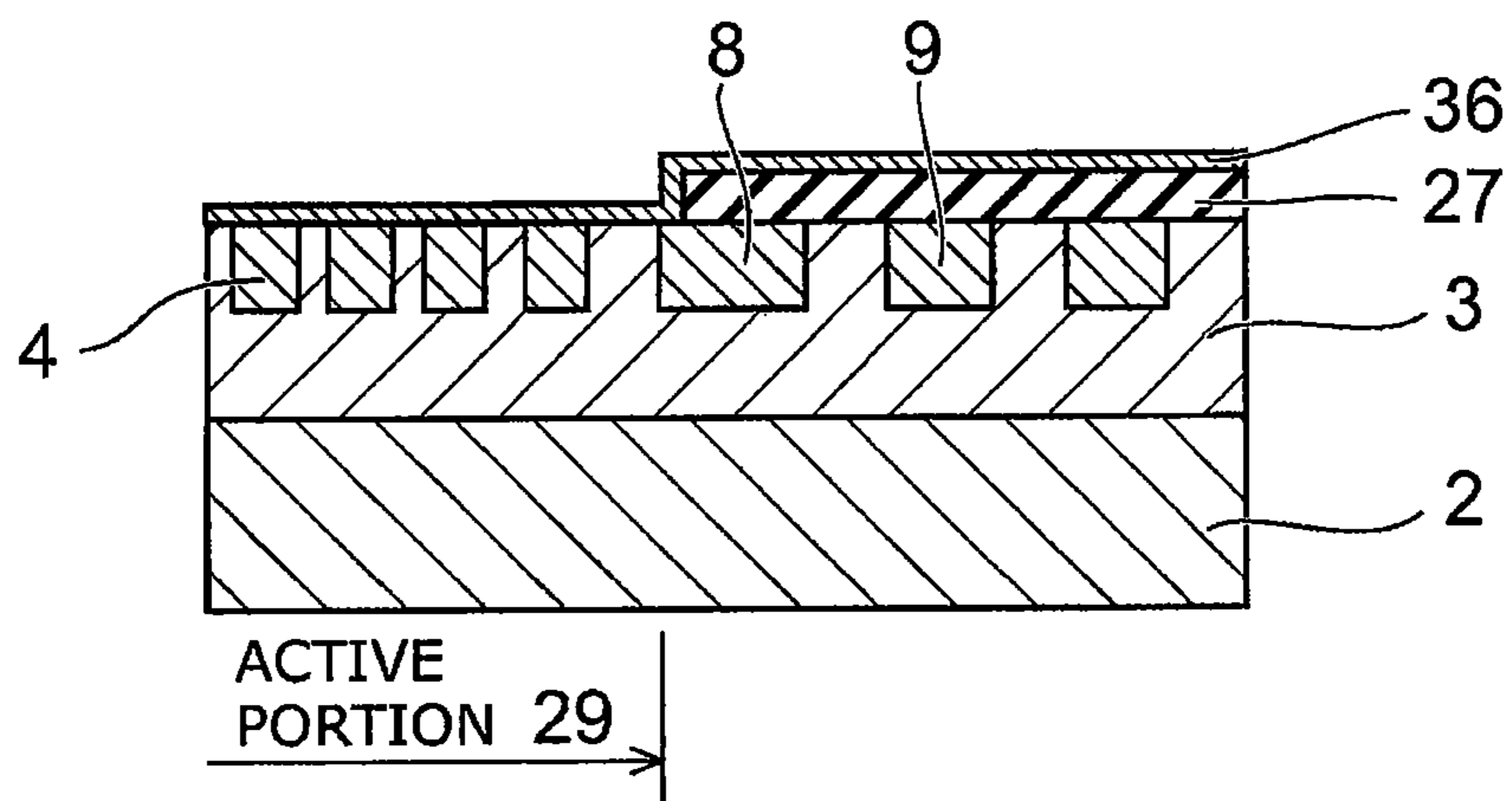


FIG. 2B

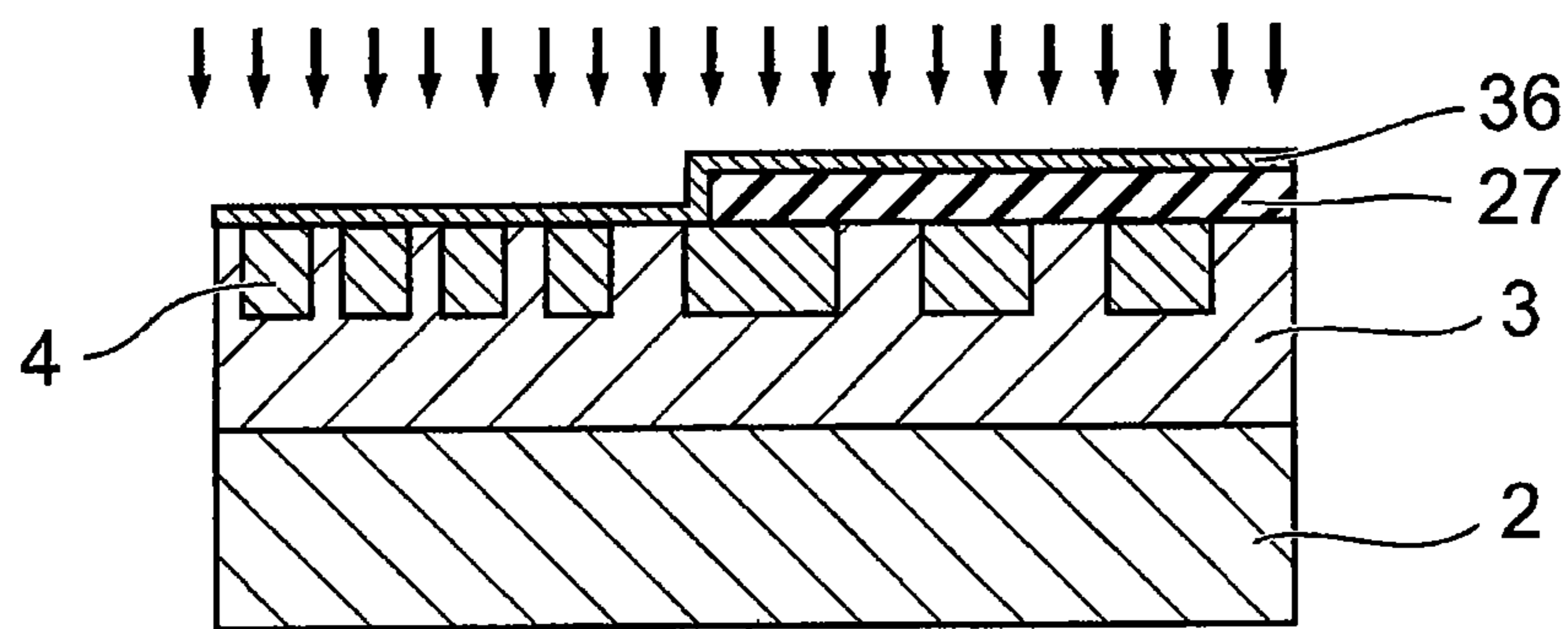


FIG. 2C

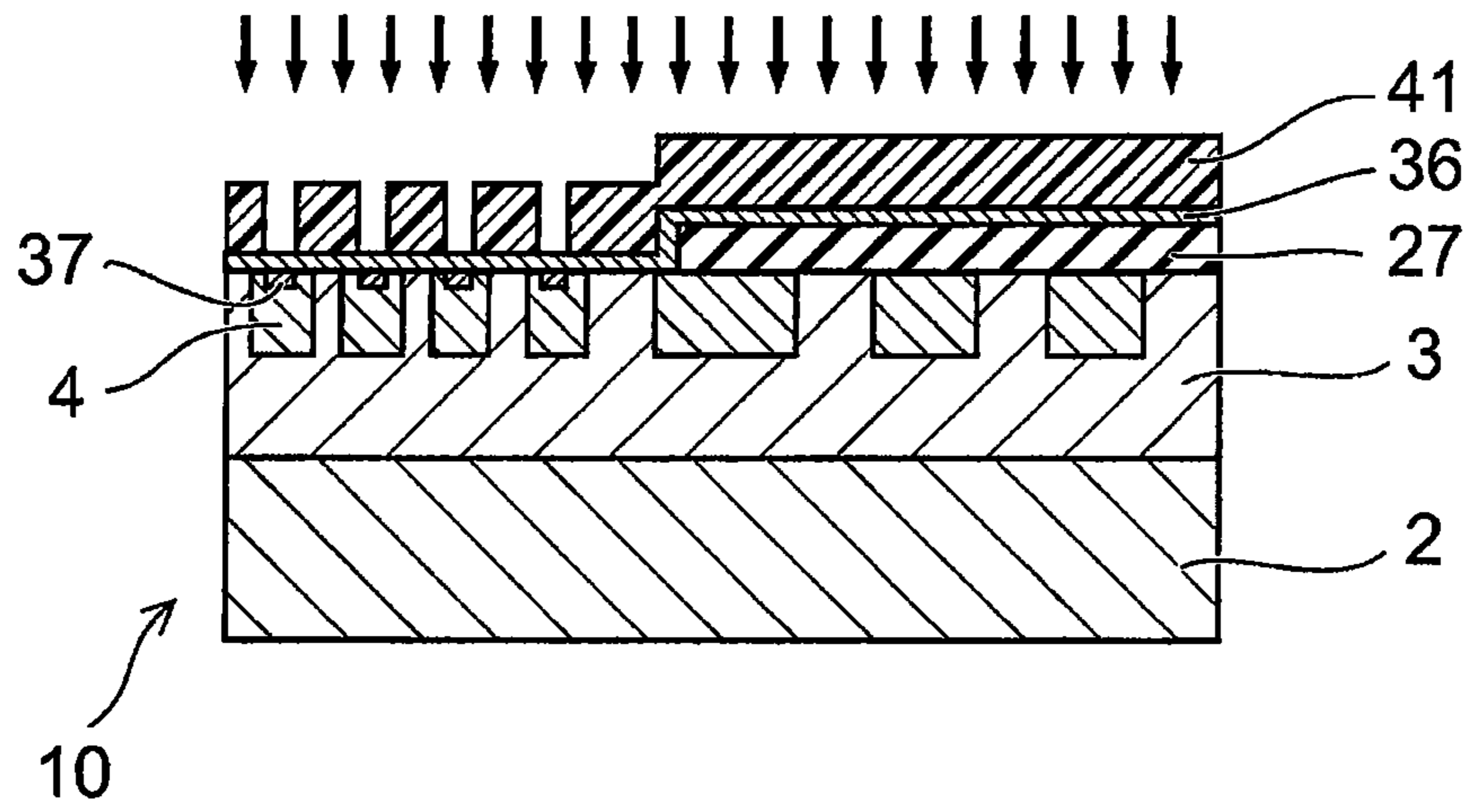


FIG. 3A

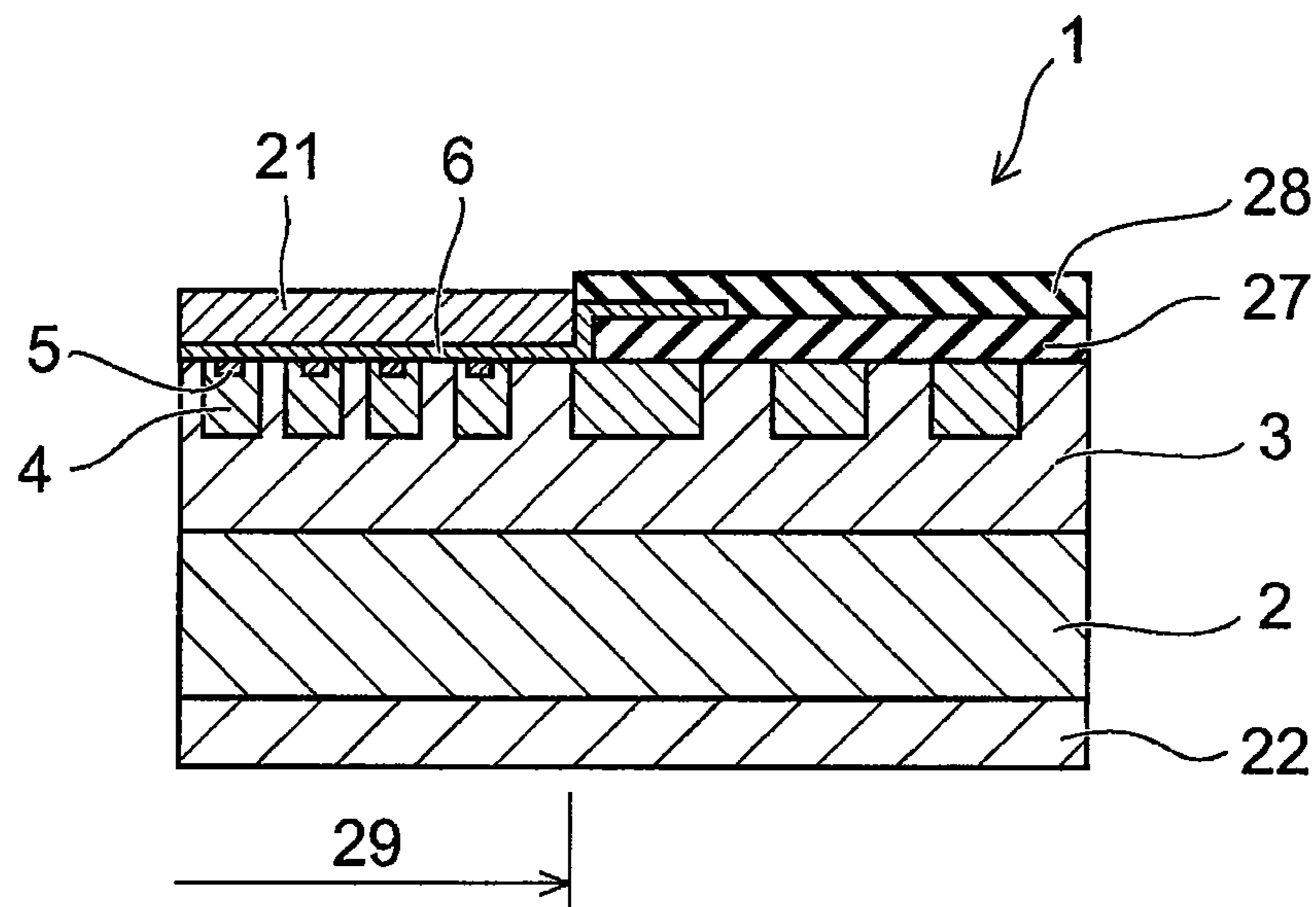


FIG. 3B

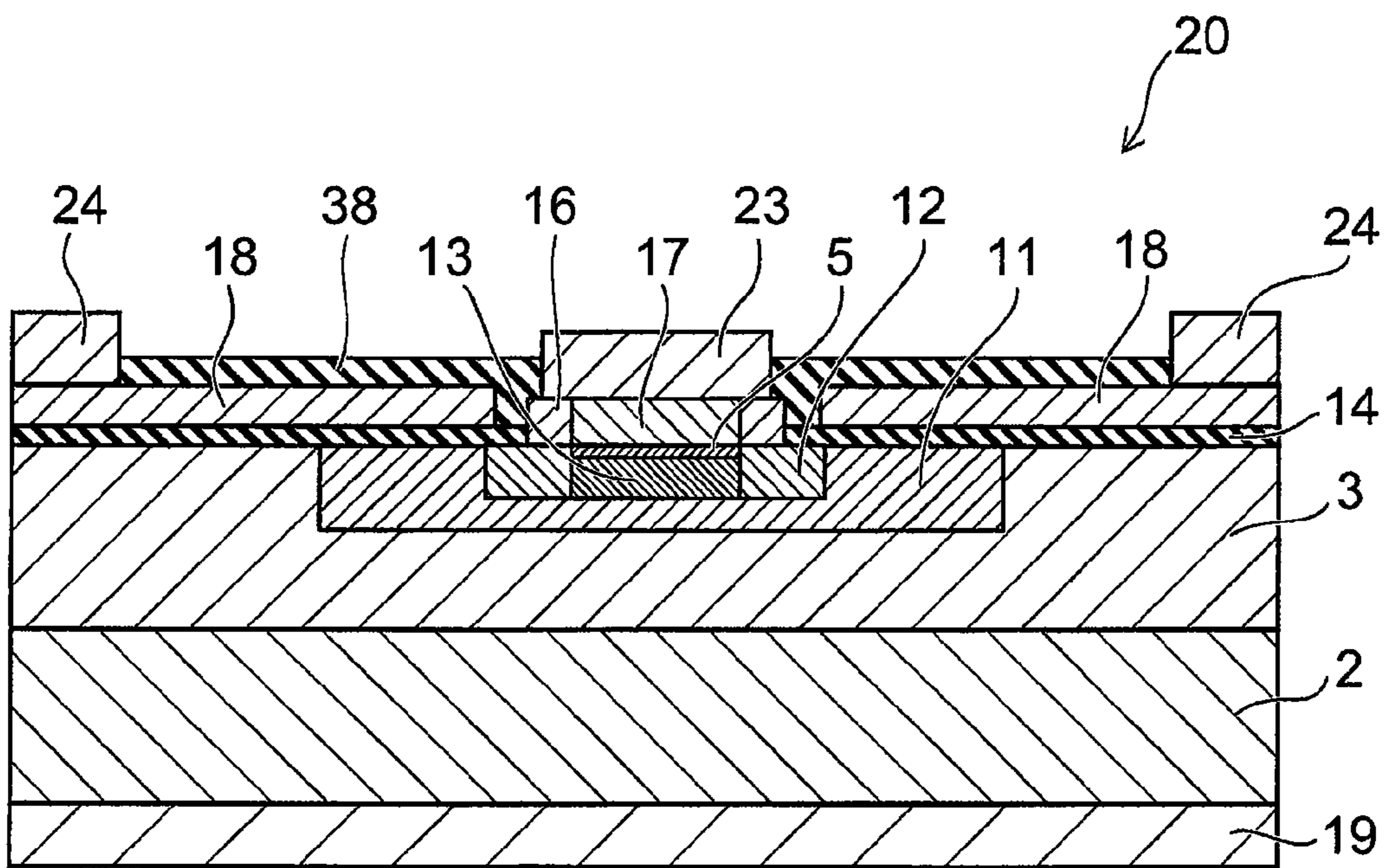


FIG. 4

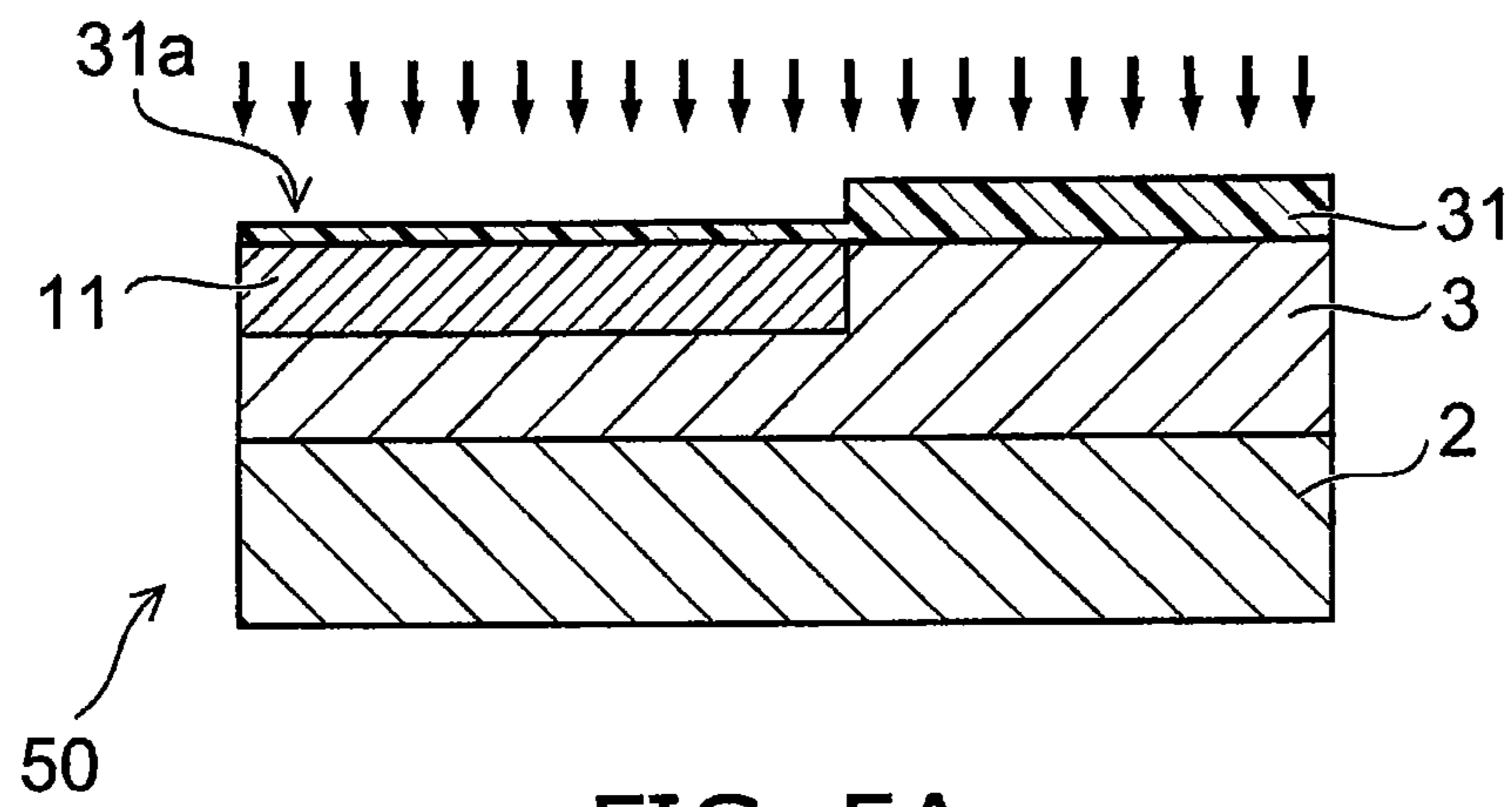


FIG. 5A

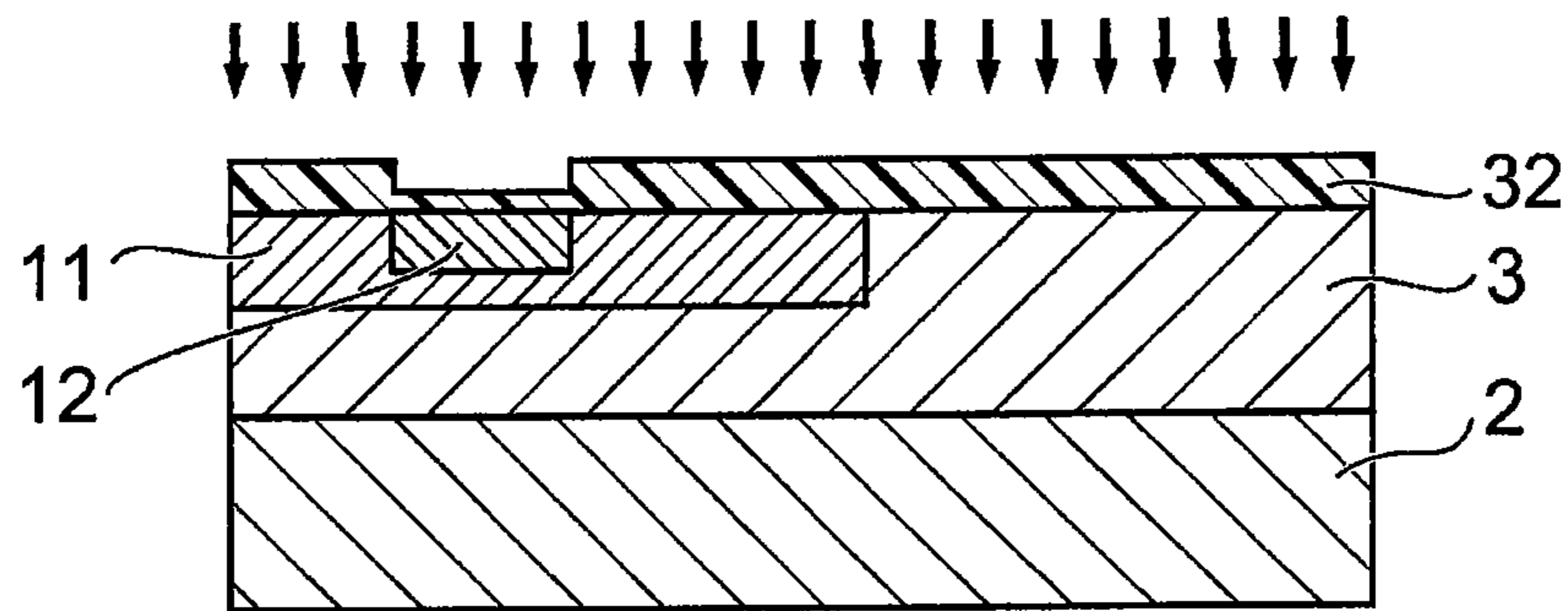


FIG. 5B

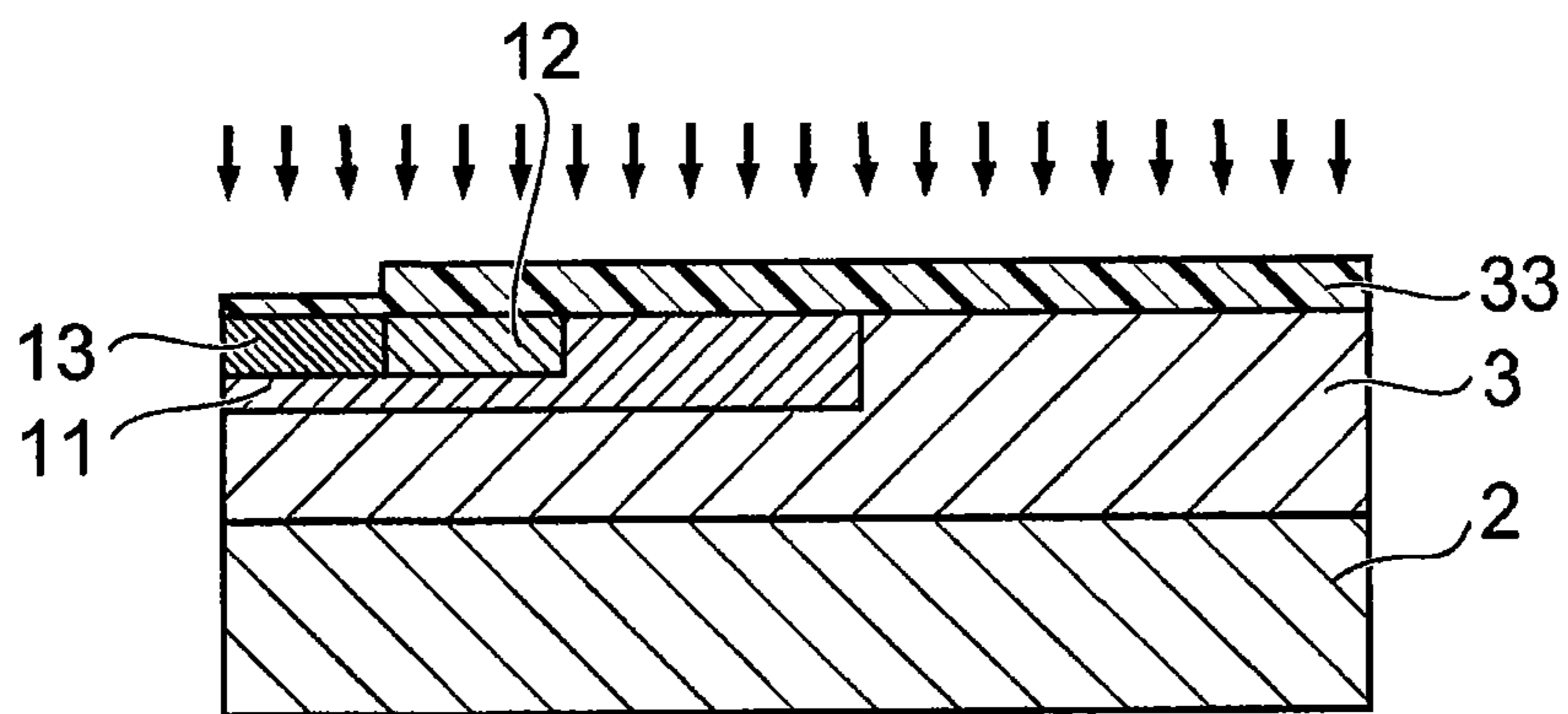


FIG. 5C

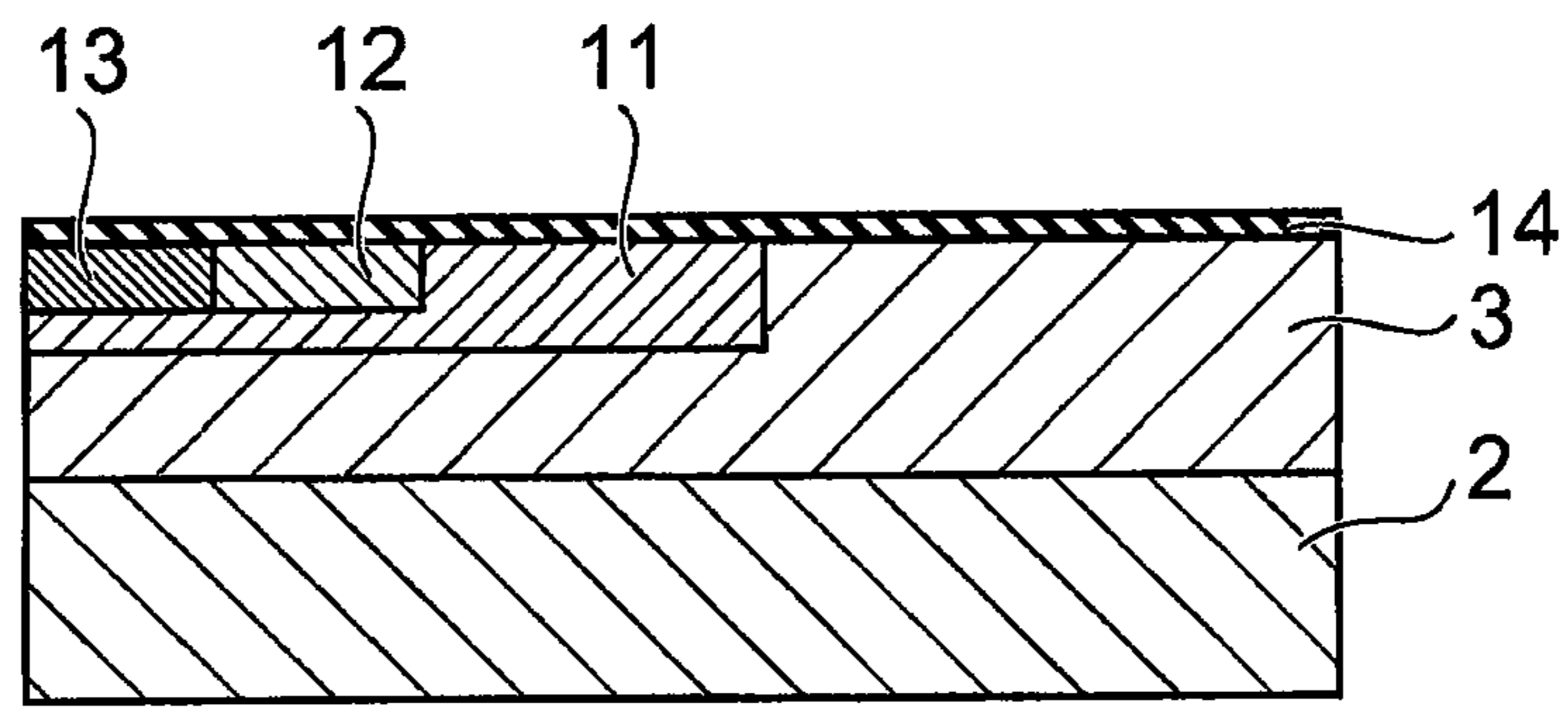


FIG. 6A

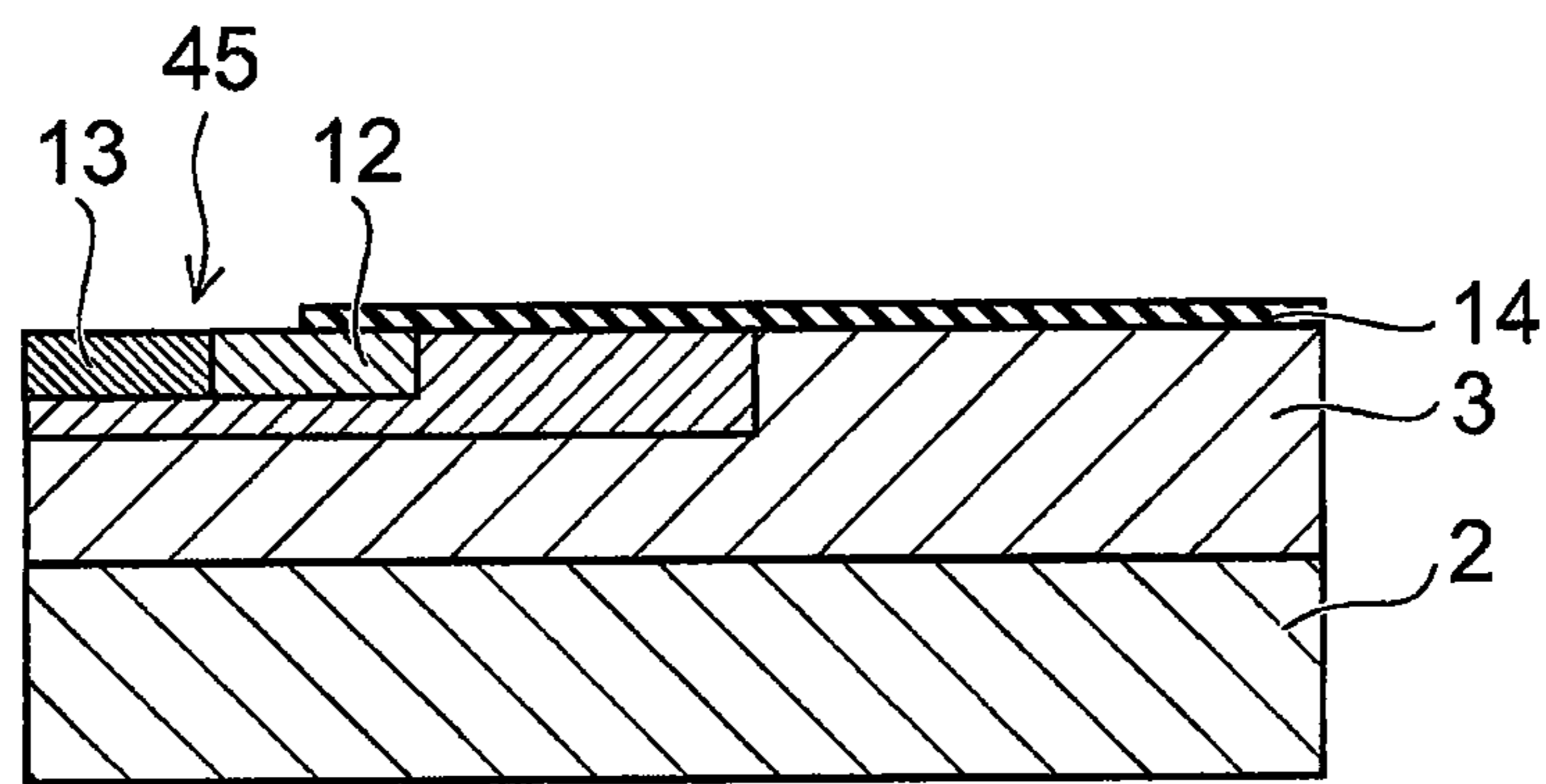


FIG. 6B

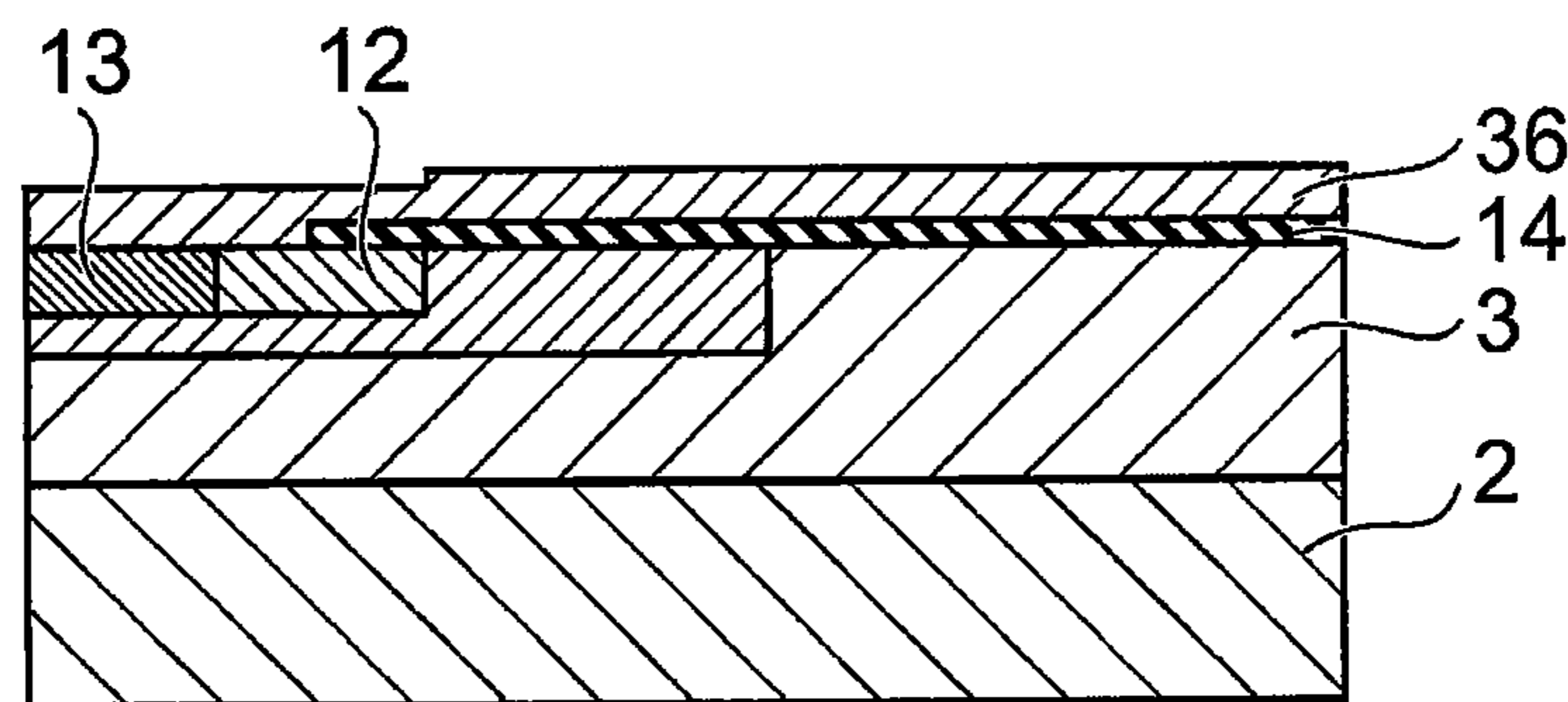


FIG. 6C

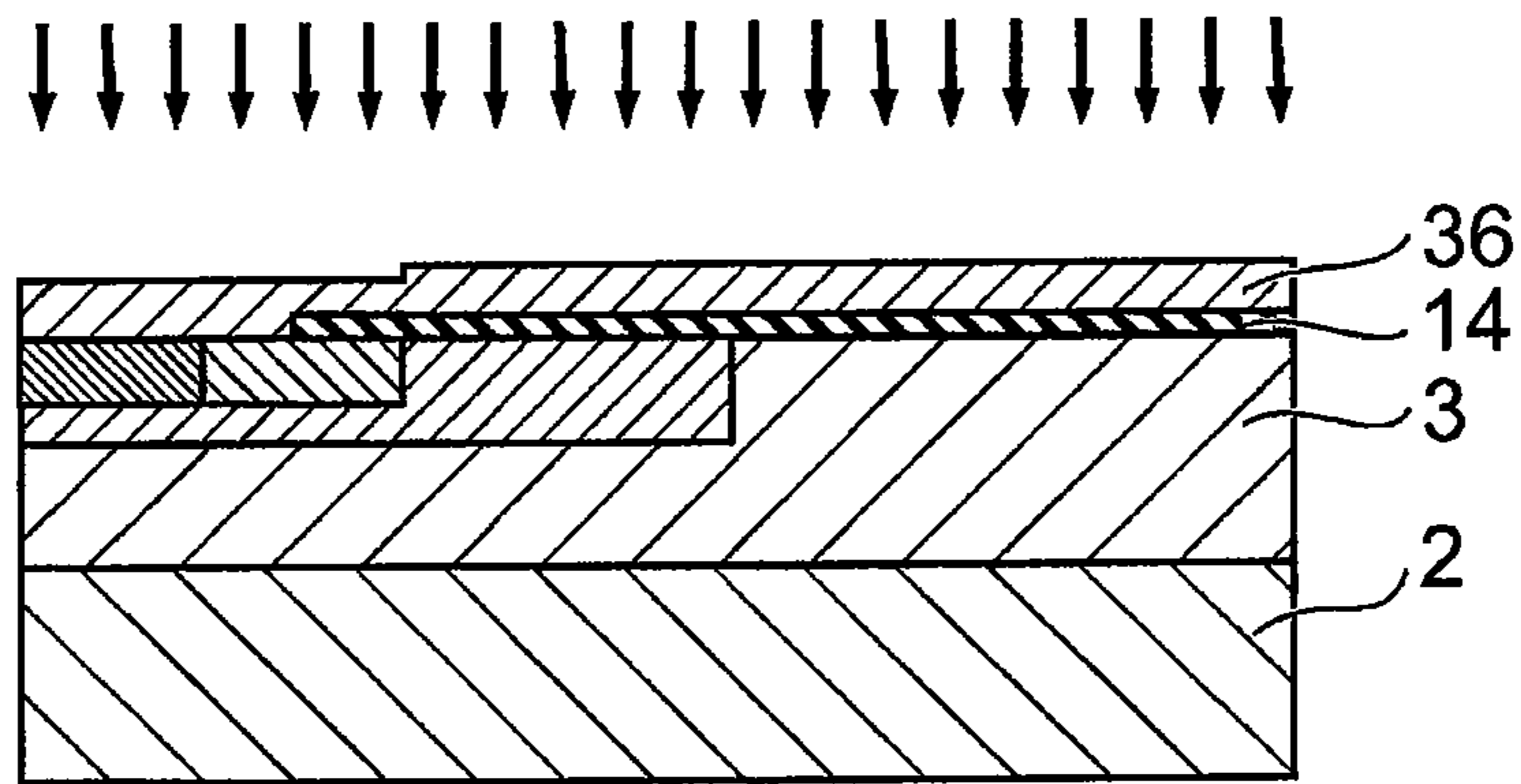


FIG. 7A

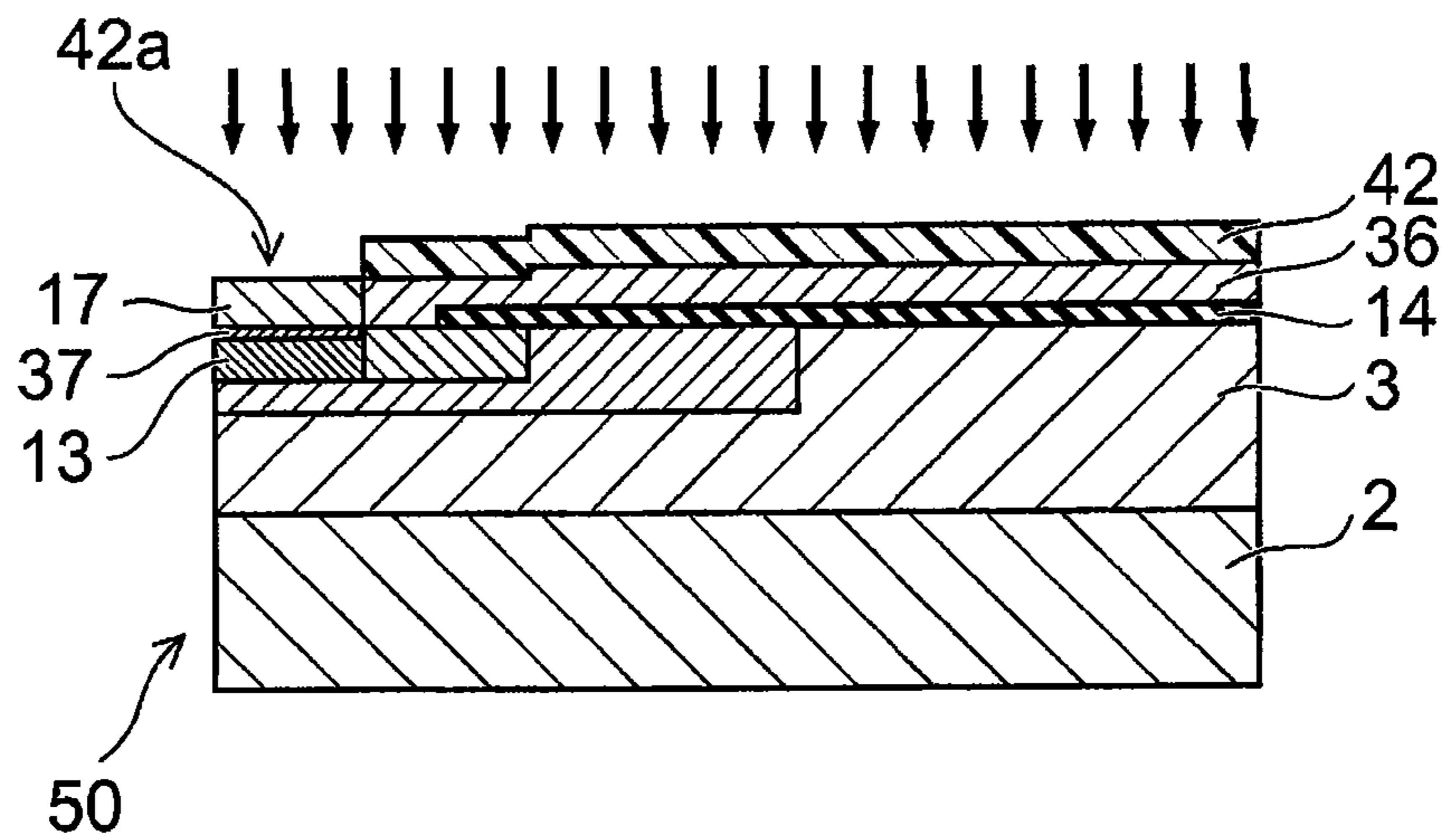


FIG. 7B

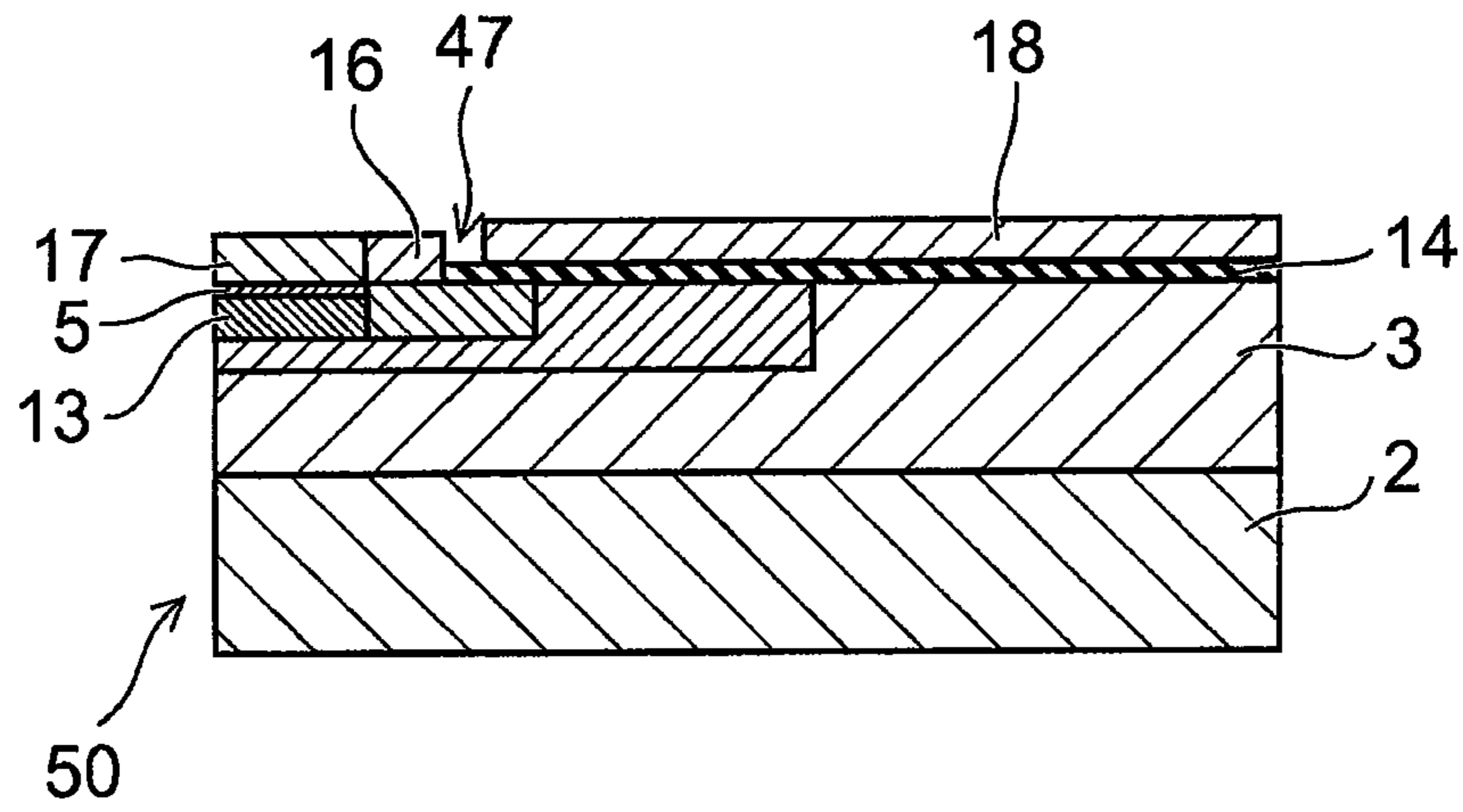


FIG. 8A

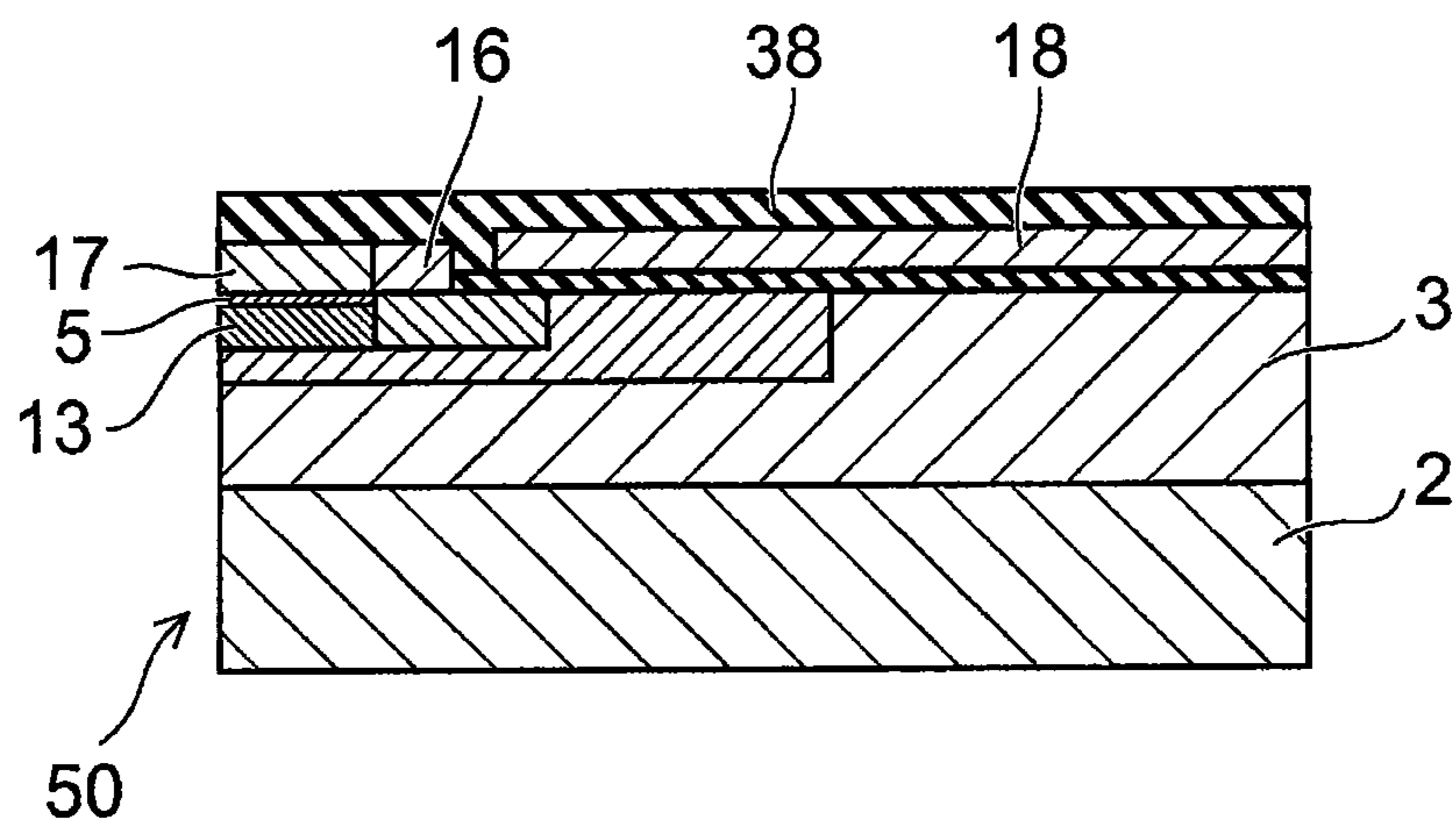


FIG. 8B

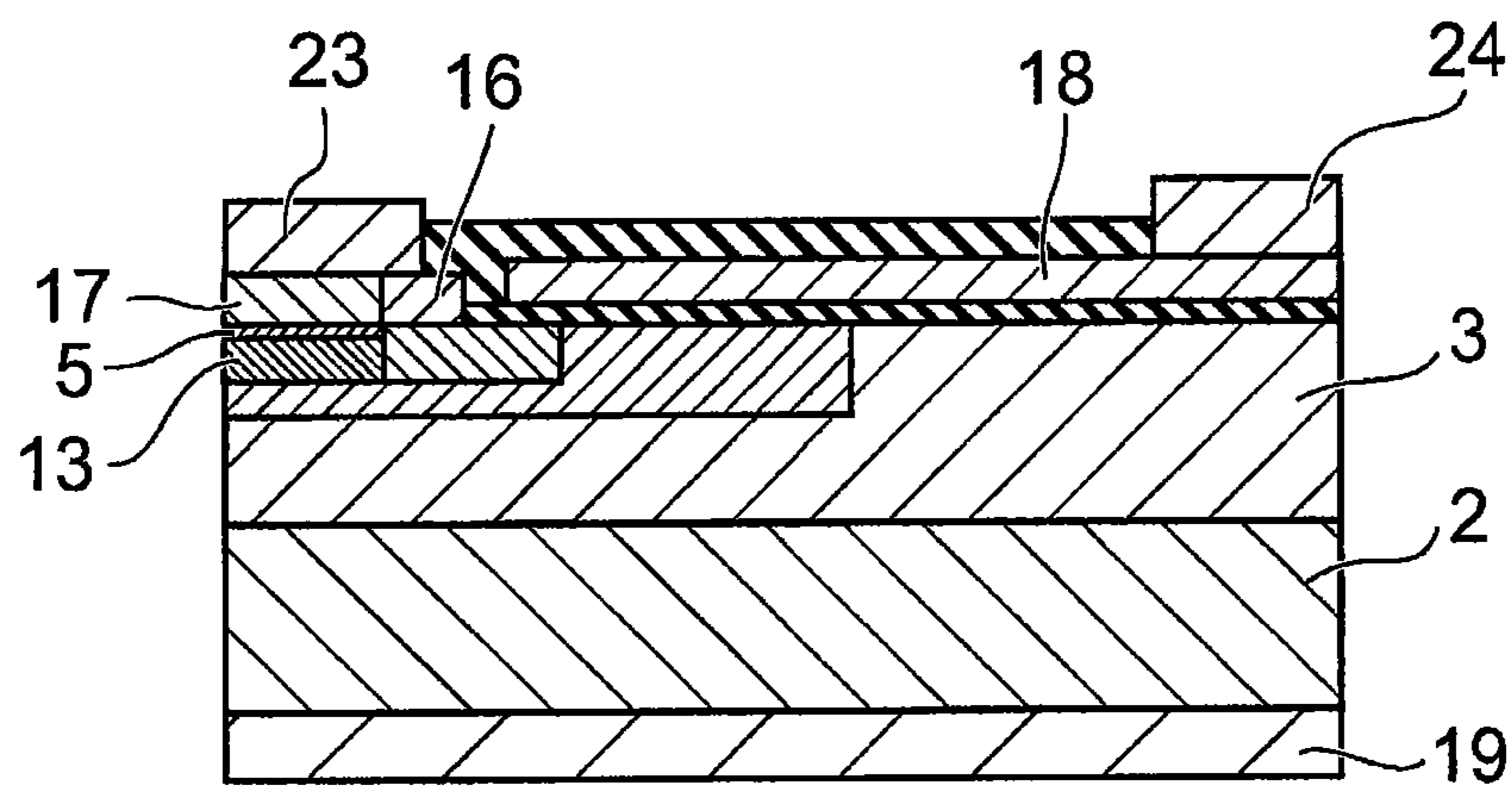


FIG. 8C

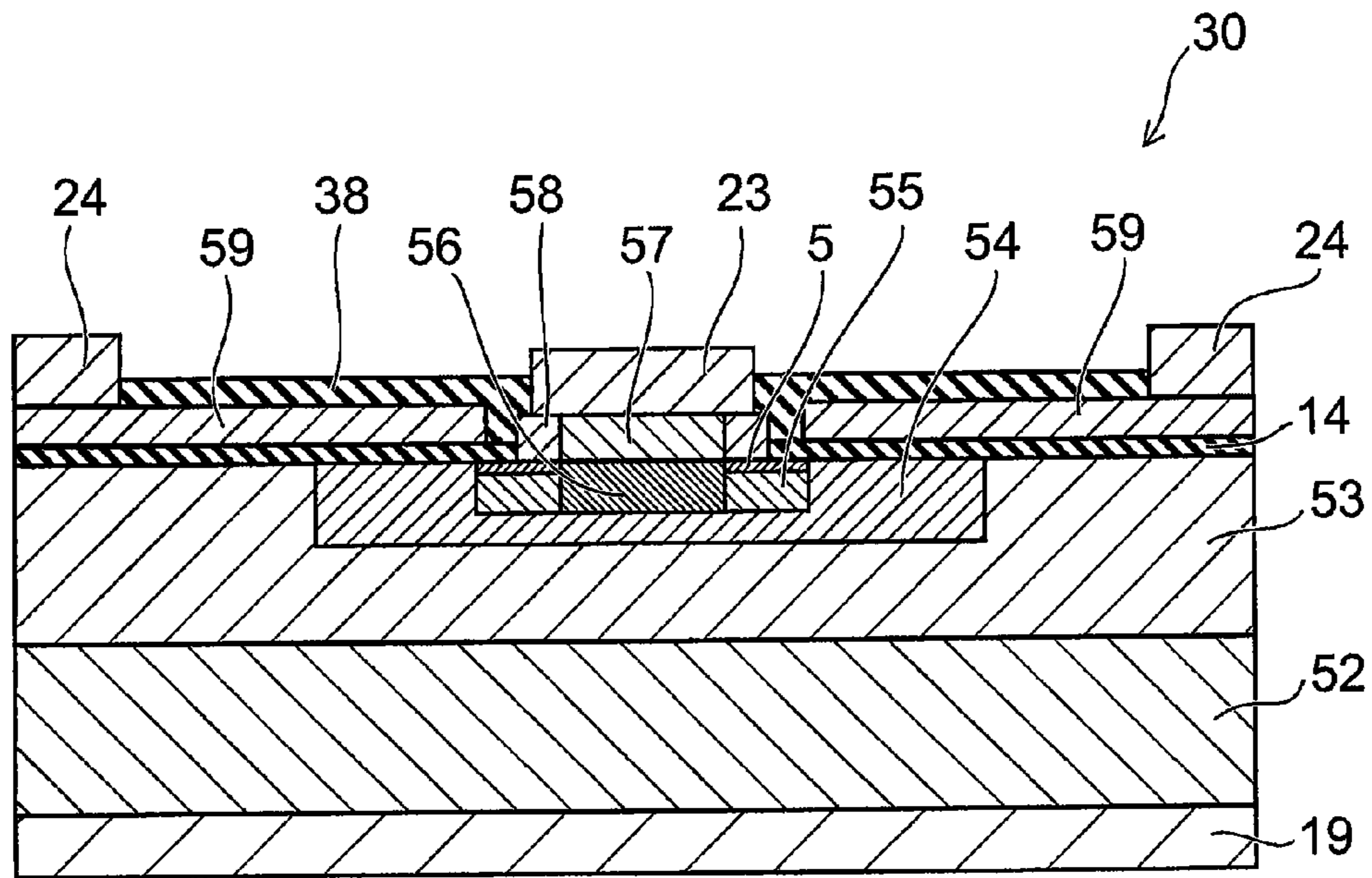


FIG. 9

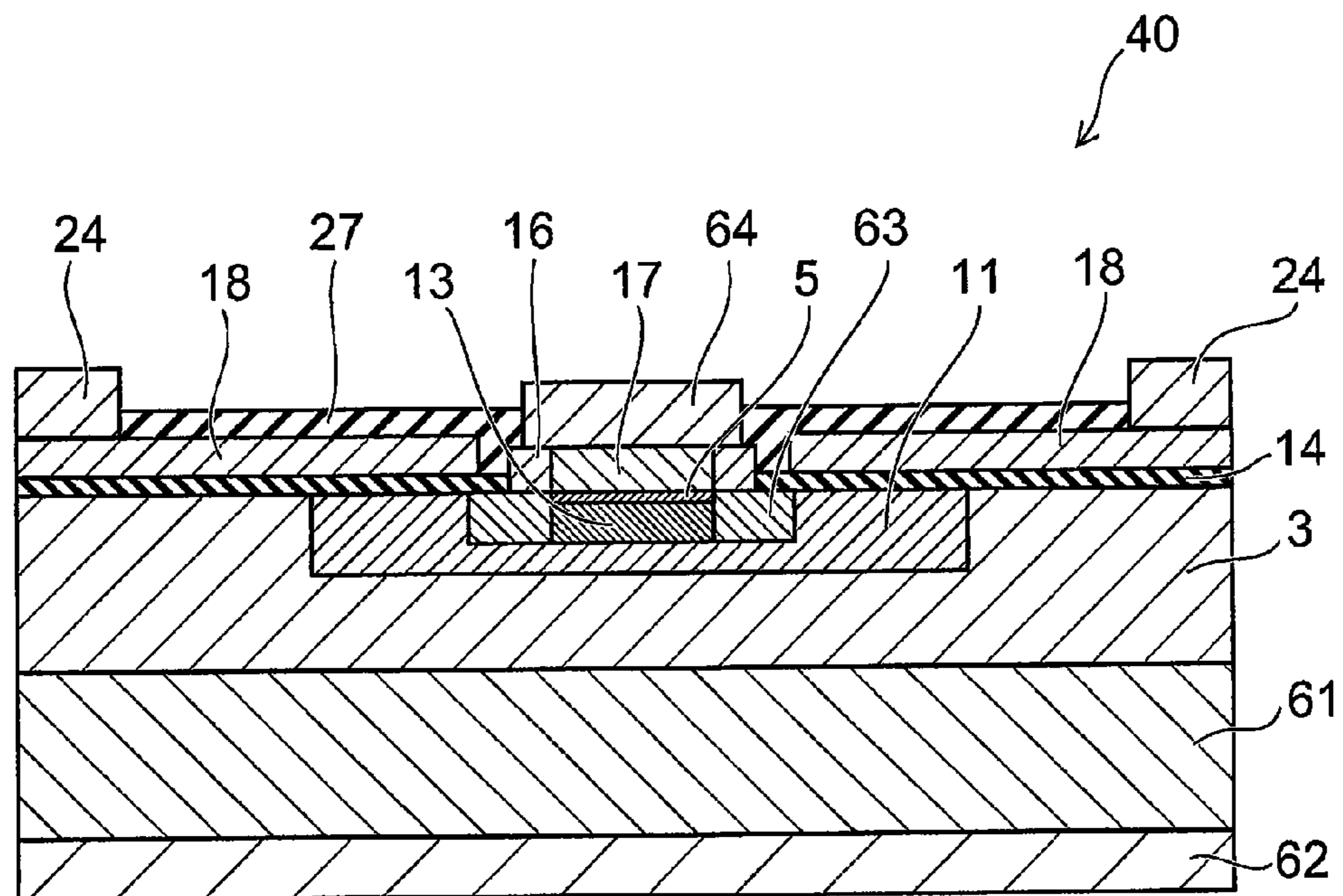


FIG. 10

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**SEMICONDUCTOR DEVICE AND METHOD
FOR MANUFACTURING SEMICONDUCTOR
DEVICE**

CROSS-REFERENCE TO RELATED
APPLICATIONS

This application is a divisional of U.S. patent application Ser. No. 13/021,400, filed on Feb. 4, 2011, which is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2010-027121, filed on Feb. 10, 2010; the entire contents of which are incorporated herein by reference.

FIELD

Embodiments described herein relate generally to a semiconductor device and a method for manufacturing the semiconductor device.

BACKGROUND

Power semiconductor devices used for power control are required to have low power loss during operation. Specifically, it is important to reduce the on-resistance in switching control. This requires a technique for reducing the internal resistance resulting from the device structure and the contact resistance between the metal electrode and the semiconductor.

Silicon carbide (SiC) is a wide gap semiconductor having a wide forbidden gap and hence is more resistant to high electric field than silicon. This enables reduction of the internal resistance. Thus, SiC is promising as a material for realizing a power semiconductor device with lower power loss. However, because SiC is a wide gap semiconductor, it is difficult to reduce the contact resistance between SiC and the metal electrode. Techniques for solving this problem are currently under study.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view showing a cross section of a semiconductor device according to a first embodiment;

FIGS. 2A to 3B are schematic views showing a manufacturing process of the semiconductor device according to the first embodiment;

FIG. 4 is a schematic view showing a cross section of a semiconductor device according to a second embodiment;

FIGS. 5A to 8C are schematic views showing a manufacturing process of the semiconductor device according to the second embodiment;

FIG. 9 is a schematic view showing a cross section of a semiconductor device according to a third embodiment; and

FIG. 10 is a schematic view showing a cross section of a semiconductor device according to a fourth embodiment.

DETAILED DESCRIPTION

In general, according to one embodiment, a semiconductor device includes a SiC layer of a first conductivity type, a SiC region of a second conductivity type, and a conductive layer of the second conductivity type. The SiC layer of the first conductivity type has a hexagonal crystal structure. The SiC region of the second conductivity type is formed in a surface of the SiC layer. The conductive layer of the second conduc-

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tivity type is provided on the SiC region and is in contact with a portion of the SiC region including SiC of a cubic crystal structure.

Embodiments will now be described with reference to the drawings. In the following embodiments, like components in the drawings are labeled with like reference numerals, with the detailed description thereof omitted as appropriate, and the different components are described as appropriate. Furthermore, unless otherwise specified, in the following description, it is assumed that the first conductivity type is N-type and the second conductivity type is P-type. (First Embodiment)

FIG. 1 is a schematic view showing a cross section of a semiconductor device according to a first embodiment. In the description of this embodiment, a diode 1 for power control formed in an N-type SiC layer is taken as an example.

As shown in FIG. 1, the diode 1 according to this embodiment includes an N-type SiC layer 3 formed on the first major surface of an N-type SiC substrate 2. The N-type SiC layer 3 has a hexagonal crystal structure. For instance, a single crystal called 4H—SiC can be used for the N-type SiC layer 3. Here, the first major surface refers to the upper major surface of the N-type SiC substrate 2 and the N-type SiC layer 3 shown in FIG. 1. This also applies to the subsequent figures.

SiC is a semiconductor which can have a cubic or hexagonal crystal structure. Depending on the difference in a crystal structure, SiC is classified into three types, i.e., 3C—SiC, 6H—SiC, and 4H—SiC. 3C—SiC is SiC of a cubic crystal structure, whereas 6H—SiC and 4H—SiC are both SiC of a hexagonal crystal structure. 6H—SiC and 4H—SiC have a wider forbidden gap than 3C—SiC, and are considered suitable as a material for power devices.

In the active portion 29 shown at the center of the cross-sectional structure in FIG. 1, a P-type SiC region 4 and a P-type conductive layer 6 doped with P-type impurity are provided in the first major surface, i.e., the surface of the N-type SiC layer 3. The P-type conductive layer 6 can be e.g. a polysilicon layer doped with P-type impurity. The P-type conductive layer 6 includes a portion in contact with the surface of the P-type SiC region 4 and an operating region 7 in which the P-type conductive layer 6 is in contact with the N-type SiC layer 3 to form a PN junction.

Furthermore, a recrystallized region 5 is provided in the portion of the P-type SiC region 4 in contact with the P-type conductive layer 6. The recrystallized region 5 includes 3C—SiC and reduces the contact resistance between the P-type conductive layer 6 and the P-type SiC region 4.

More specifically, the forbidden gap of 3C—SiC is approximately 2.23 eV, which is narrower than that of 6H—SiC, approximately 2.93 eV and that of 4H—SiC, approximately 3.26 eV, both hexagonal crystals. Hence, as compared with the case where the P-type SiC region 4 of hexagonal crystal is brought into direct contact with the P-type conductive layer 6, the contact resistance can be reduced by bringing them into contact via 3C—SiC.

On the other hand, around the active portion 29, a guard ring region 8 is provided in contact with both ends of the P-type conductive layer 6. Furthermore, outside the guard ring region 8, a P-region 9 is formed in contact with a passivation film 27. The guard ring region 8 and the P-region 9 increase the breakdown voltage in the peripheral portion of the operating region 7. This can prevent edge breakdown in the peripheral portion.

In the diode 1 according to this embodiment, in the off-mode in which the operating region 7 is reverse biased, the PN junction between the P-type SiC region 4 and the N-type SiC

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layer **3** is also reverse biased, and a depletion layer extends in the N-type SiC layer **3**. This can increase the reverse breakdown voltage of the diode **1**.

On the other hand, in the on-mode in which the operating region **7** is forward biased, an on-current flows between the anode electrode **21** and the cathode electrode **22**. Here, the on-current flows through the operating region **7** including the PN junction between the P-type conductive layer **6** and the N-type SiC layer **3**, the PN junction having a lower built-in voltage than the PN junction between the P-type SiC region **4** and the N-type SiC layer **3**.

Furthermore, if the diode **1** during on-mode operation is applied with a surge voltage, a current flows also in the PN junction between the P-type SiC region **4** and the N-type SiC layer **3** in addition to the operating region **7**. Here, the recrystallized region **5** can be provided between the P-type SiC region **4** and the P-type conductive layer **6** to reduce the contact resistance. Then, the excessive current flowing in the operating region **7** can be smoothly shunted through the PN junction between the P-type SiC region **4** and the N-type SiC layer **3**. This can increase the surge breakdown voltage in the on-mode of the diode **1**.

Next, a process for manufacturing the diode **1** according to this embodiment is described with reference to FIGS. **2A** to **3B**. Here, FIGS. **2A** to **3B** are schematic views showing the right half of the cross-sectional structure of the diode **1** shown in FIG. **1**.

FIG. **2A** is a partial cross-sectional view of a SiC wafer **10**. FIG. **2A** schematically shows the process for forming a P-type SiC region **4**, a guard ring region **8**, and a P-region **9** by ion implantation of P-type impurity into the first major surface of the N-type SiC layer **3**. In the SiC wafer **10**, an N-type SiC layer **3** with low impurity concentration is epitaxially grown on an N-type 4H—SiC substrate **2** doped with high impurity concentration. The N-type SiC layer **3** is also made of 4H—SiC and has a hexagonal crystal structure.

First, on the first major surface of the N-type SiC layer **3**, for instance, a thermal oxide film having a thickness of approximately 40 nm is formed by the dry oxidation method. Subsequently, a silicon dioxide film **31** (SiO₂ film) having a thickness of 2 μm is formed by the thermal CVD method. Furthermore, an ion implantation pattern is formed in the SiO₂ film **31** by photolithography. Here, the SiO₂ film can be removed by RIE (reactive ion etching) with a thin film **31a** left in a portion where P-type impurity is to be implanted. This can prevent, for instance, damage to the surface of the N-type SiC layer **3** due to the RIE plasma and contamination in the subsequent process.

Next, the SiO₂ film **31** is used as an implantation mask to ion-implant aluminum (Al) as P-type impurity into the region where a P-type SiC region **4**, a guard ring region **8**, and a P-region **9** are to be formed. Here, to reduce implantation damage, the SiC wafer **10** can be heated to 500° C. during the ion implantation.

Despite the heat treatment of the SiC wafer **10** performed after the ion implantation, Al implanted into the N-type SiC layer **3** remains at the implanted position without redistribution. Hence, in order to form a desired distribution of P-type impurity in the first major surface of the N-type SiC layer **3**, for instance, multistage ion implantation may be performed with the dose amount and implantation energy varied as shown in TABLE 1.

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TABLE 1

	DOSE AMOUNT ($\times 10^{13}$ cm ⁻²)	IMPLANTATION ENERGY (keV)
FIRST ION IMPLANTATION	0.725	40
SECOND ION IMPLANTATION	2.42	100
THIRD ION IMPLANTATION	2.42	200
FOURTH ION IMPLANTATION	2.42	300
FIFTH ION IMPLANTATION	4.03	350

Next, the SiO₂ film **31** is removed by wet etching with BHF (buffered hydrogen fluoride). Subsequently, activation annealing is performed in an Ar atmosphere at 1900° C. for 5 minutes.

Subsequently, a thermal oxide film is formed approximately 40 nm on the first major surface of the N-type SiC layer **3** by the dry oxidation method. Furthermore, for instance, a SiO₂ film is deposited by the LP-CVD (Low Pressure Chemical Vapor Deposition) method to form a passivation film **27** of approximately 1 μm.

Next, as shown in FIG. **2B**, the passivation film **27** in the active portion **29** is removed by wet etching. Subsequently, for instance, a polysilicon layer **36** is deposited by the LP-CVD method. Thus, a polysilicon layer **36** constituting a P-type conductive layer **6** can be formed on the N-type SiC layer **3** and the P-type SiC region **4** provided on the first major surface of the N-type SiC layer **3**.

Furthermore, as shown in FIG. **2C**, P-type impurity is ion-implanted into the polysilicon layer **36**. For instance, boron (B) can be used as the P-type impurity. As the implantation condition, the dose amount can be set to 5×10^{14} cm⁻², and the implantation energy can be set to 20 keV.

Alternatively, the polysilicon layer **36** can also be formed as a conductive polysilicon layer, which is doped with P-type impurity during deposition. In this case, the ion implantation of P-type impurity shown in FIG. **2C** can be omitted.

Next, as shown in FIG. **3A**, P-type impurity is ion-implanted into the P-type SiC region **4** and the polysilicon layer **36**. Thus, the polysilicon layer **36** is doped with P-type impurity, and implantation damage is formed in the portion of the P-type SiC region **4** in contact with the polysilicon layer **36**.

First, an implantation mask **41** for selective implantation of P-type impurity is formed. The implantation mask can be made of e.g. a photoresist film. As shown in FIG. **3A**, an opening is provided in the photoresist film **41** above the P-type SiC region **4** by photolithography.

Next, B can be selected as P-type impurity and ion-implanted under the condition of, e.g., a dose amount of 3×10^{15} cm⁻² and an implantation energy of 300 keV. While the ion implantation is performed, the SiC wafer is maintained at room temperature to form a damage region **37** in the surface portion of the P-type SiC region **4**, so that the crystal can be turned amorphous, for instance. The implantation energy can be set in consideration of the thickness of the polysilicon layer **36** so that the damage region **37** is formed in the surface layer of the P-type SiC region **4**.

Next, as shown in FIG. **3B**, the polysilicon layer **36** is selectively removed by dry etching and left only in the active portion **29** and its outer peripheral portion.

Subsequently, the P-type SiC region **4** and the polysilicon layer **36** are heat treated. Thus, the P-type impurity implanted into the polysilicon layer **36** is activated, and the amorphous layer of the damage region **37** formed in the surface portion of the P-type SiC region **4** is recrystallized to form a recrystallized region **5** including 3C—SiC.

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For instance, by heat treatment of the SiC wafer **10** in a forming gas atmosphere (a mixture of hydrogen and nitrogen) at 900° C. for 10 minutes, the P-type SiC region **4** and the polysilicon layer **36** can be heat treated. Thus, B as P-type impurity in the polysilicon layer **36** is activated to form a P-type conductive layer **6**. Furthermore, a low resistance contact is formed between the P-type conductive layer **6** and the recrystallized region **5** including 3C—SiC, which is formed between the P-type SiC region **4** and the P-type conductive layer **6**.

Next, an anode electrode **21** is formed on the surface of the P-type conductive layer **6**. The anode electrode **21** can be made of e.g. metal aluminum. As shown in FIG. 3B, after forming the anode electrode **21** made of metal aluminum on the P-type conductive layer **6**, annealing is performed in a forming gas atmosphere at 450° C. for 10 minutes. Thus, ohmic contact can be formed between the P-type conductive layer **6** and the anode electrode **21**.

On the surface outside the active portion **29**, a surface protective film **28** is formed from a photosensitive polyimide film. Furthermore, a cathode electrode **22** is formed on the second major surface of the N-type SiC substrate **2**. Thus, the diode **1** is completed.

In the method for manufacturing the diode **1** according to this embodiment, after forming a polysilicon layer **36** in contact with the P-type SiC region **4** of the 4H—SiC structure, P-type impurity is ion-implanted to form a damage region **37**. Then, by simply performing heat treatment, a low resistance contact can be formed between the P-type conductive layer **6** and the P-type SiC region **4**.

The heat treatment for recrystallizing the damage region **37** to form 3C—SiC can be performed at a temperature of 1000° C. or less. Thus, without degrading the PN junction formed at the interface of the P-type conductive layer **6** and the N-type SiC layer **3**, a low resistance contact can be formed between the P-type conductive layer **6** and the P-type SiC region **4**. Furthermore, no degradation is caused at the interface of the passivation film **27** and the N-type SiC layer **3** outside the active portion **29**. Hence, there is no decrease of breakdown voltage and no increase of leakage current in the peripheral portion.

That is, the method for manufacturing a semiconductor device according to this embodiment can be easily performed and is suitable to manufacture the diode **1**, for instance.

In the description of this embodiment, the P-type conductive layer is made of polysilicon as an example, but is not limited thereto. For instance, a single crystal silicon layer or a compound semiconductor such as GaAs can also be used. This also applies to the embodiments described below.

(Second Embodiment)

FIG. 4 is a schematic view showing a cross section of a semiconductor device according to a second embodiment. In the description of this embodiment, a power MOSFET **20** formed in an N-type SiC layer **3** is taken as an example. FIG. 4 schematically shows a cross section of a unit cell of the power MOSFET **20**.

As shown in FIG. 4, the power MOSFET **20** includes a P-type base region **11** as a first semiconductor region, an N-type source region **12** as a second semiconductor region, and a P-type contact region **13** as a third semiconductor region. The P-type base region **11** is provided in the first major surface, i.e., the surface of the N-type SiC layer **3** having a hexagonal crystal structure. The N-type source region **12** is selectively provided in the surface of the P-type base region **11**. The P-type contact region **13** is selectively provided in the surface of the P-type base region **11** adjacent to the N-type source region **12**.

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Furthermore, as shown in FIG. 4, a gate electrode **18** is provided above the P-type base region **11** via a gate oxide film **14**. A gate wiring **24** is connected to the surface of the gate electrode **18**.

An N-type conductive layer **16** as a first conductive layer and a P-type conductive layer **17** as a second conductive layer are provided on the N-type source region **12** and the P-type contact region **13**, respectively. A recrystallized region **5** including 3C—SiC is formed in the portion of the P-type contact region **13** in contact with the P-type conductive layer **17**.

Furthermore, a source wiring **23** is provided on the N-type conductive layer **16** and the P-type conductive layer **17**. A drain electrode **19** is provided on the second major surface of the N-type SiC substrate **2**.

The power MOSFET **20** according to this embodiment is configured so that the N-type conductive layer **16** and the P-type conductive layer **17** are in contact with the N-type source region **12** and the P-type contact region **13**, respectively, to reduce the contact resistance. Furthermore, the recrystallized region **5** including 3C—SiC is formed in the surface of the P-type contact region **13** to reduce the P-type contact resistance.

The N-type conductive layer **16** and the P-type conductive layer **17** can be made of materials such as polysilicon, single crystal silicon, and compound semiconductor, which do not react with each other at the heat treatment temperature in forming the recrystallized region **5**.

Alternatively, the N-type conductive layer **16** and the P-type conductive layer **17** can also be made of metal materials, such as nickel (Ni), suitable for N-type SiC and P-type SiC, respectively. However, in the case of using metal materials, the metal materials need to be spaced from each other to avoid reaction therebetween. In contrast, as described above, in the case of using materials such as polysilicon which do not react with each other, the N-type conductive layer **16** and the P-type conductive layer **17** can be provided in contact with each other. This is advantageous to reduce electrode spaces for miniaturization.

FIGS. 5A to 8C are partial cross-sectional views of a SiC wafer **50** showing a process for manufacturing the power MOSFET **20** according to this embodiment. Here, FIGS. 5A to 8C each show the right half of the cross-sectional structure of the power MOSFET **20** shown in FIG. 4.

FIG. 5A is a cross-sectional view schematically showing a process for forming a P-type base region **11** by ion implantation of P-type impurity into the first major surface of the N-type SiC layer **3**. The N-type SiC layer **3** is made of e.g. 4H—SiC and has a hexagonal crystal structure.

First, on the first major surface of the N-type SiC layer **3**, for instance, a SiO₂ film **31** having a thickness of 2 μm is used to form an implantation mask. Here, a thin film **31a** is left in a portion where P-type impurity is to be ion-implanted.

Next, aluminum (Al) as P-type impurity is ion-implanted into the region where a P-type base region **11** is to be formed. Here, the SiC wafer **50** can be heated to 500° C. Furthermore, multistage ion implantation may be performed under the implantation condition shown in TABLE 1.

Next, the SiO₂ film **31** is removed by wet etching with BHF. Then, as an implantation mask, a SiO₂ film **32** having a thickness of 1 μm is again formed. Subsequently, as shown in FIG. 5B, an opening is formed in a portion of the SiO₂ film **32** where an N-type source region **12** is to be formed. Then, the SiO₂ film **32** is used as an implantation mask to ion-implant N-type impurity. For instance, phosphorus (P) can be used as the N-type impurity. The ion implantation may be multistage implantation performed under the implantation condition

shown in TABLE 2. This implantation can be performed as high temperature implantation with the SiC wafer **50** heated to 500° C.

TABLE 2

	DOSE AMOUNT ($\times 10^{14}$ cm $^{-2}$)	IMPLANTATION ENERGY (keV)
FIRST ION IMPLANTATION	5.0	40
SECOND ION IMPLANTATION	5.0	70
THIRD ION IMPLANTATION	10.0	100
FOURTH ION IMPLANTATION	10.0	150
FIFTH ION IMPLANTATION	20.0	200
SIXTH ION IMPLANTATION	20.0	250

Next, the SiO₂ film **32** is removed. Then, as an implantation mask, a SiO₂ film **33** having a thickness of 1 μ m is again formed. Subsequently, in a portion of the SiO₂ film where a P-type contact region **13** is to be formed, the SiO₂ film is etched to form an opening. Thus, an implantation mask is formed.

As shown in FIG. 5C, the SiO₂ film **33** is used as an implantation mask to ion-implant Al as P-type impurity, for instance. The ion implantation may be multistage implantation performed under the implantation condition shown in TABLE 2. The implantation can be performed as high temperature implantation with the SiC wafer **50** heated to 500° C.

As described above, after ion implantation for the P-type base region **11**, the N-type source region **12**, and the P-type contact region **13**, activation annealing is performed in an Ar atmosphere at 1900° C. for 5 minutes.

Next, as shown in FIG. 6A, the first major surface of the N-type SiC layer **3** is dry oxidized to form a gate oxide film **14**.

Subsequently, as shown in FIG. 6B, the gate oxide film **14** formed on the surface of the N-type source region **12** and the P-type contact region **13** is partly etched away to form a contact window **45**.

Furthermore, as shown in FIG. 6C, on the first major surface of the N-type SiC layer **3**, for instance, a polysilicon layer **36** having a thickness of approximately 0.3 μ m is formed. The polysilicon layer **36** can be deposited by the LP-CVD method.

The polysilicon layer **36** can be a conductive polysilicon layer, which is doped with N-type impurity or P-type impurity during deposition.

Next, as shown in FIG. 7A, arsenic (As) as N-type impurity is ion-implanted into the entire surface of the polysilicon layer **36**. As the implantation condition, for instance, the dose amount can be set to 1×10^{15} cm $^{-2}$, and the implantation energy can be set to 40 keV.

Next, a photoresist film is patterned by photolithography to form an implantation mask **42** on the surface of the polysilicon layer **36**. In the implantation mask **42**, an opening **42a** is formed above the P-type contact region **13**.

Subsequently, as shown in FIG. 7B, boron (B) as P-type impurity is ion-implanted at the room temperature. Here, the implantation amount and implantation energy of boron are set so as to turn the polysilicon layer **36** into a P-type conductive layer **17** and to form a damage region **37** in the portion of the P-type contact region **13** in contact with the polysilicon layer **36**. For instance, the dose amount can be set to 3×10^{15} cm $^{-2}$, and the implantation energy can be set to 150 keV.

Next, heat treatment is performed in a forming gas atmosphere at 900° C. for 10 minutes. Thus, the N-type impurity (As) and P-type impurity ion-implanted into the polysilicon

layer **36** are activated. Furthermore, the damage region **37** formed in the surface portion of the P-type contact region **13** can be recrystallized to form a recrystallized region **5** including 3C—SiC.

Next, as shown in FIG. 8A, the polysilicon layer **36** is patterned to form an isolation trench **47** at the end portion of the gate oxide film **14** on the contact window **45** side. Thus, the polysilicon layer **36** turned into an N-type conductive layer can be separated into a gate electrode **18** and an N-type conductive layer **16**.

Next, as shown in FIG. 8B, an interlayer insulating film **38** is formed on the surface of the SiC wafer **50**.

Furthermore, as shown in FIG. 8C, a contact window is opened in the interlayer insulating film **38**. A source wiring **23** is formed in contact with the P-type conductive layer **17** and the N-type conductive layer **16**. Furthermore, a gate wiring **24** is formed in contact with the gate electrode **18**.

The source wiring **23** and the gate wiring **24** can be made of e.g. metal aluminum. By annealing in a forming gas atmosphere at 450° C. for 10 minutes, ohmic contact can be formed between the source wiring **23** and the P-type conductive layer **17**, between the source wiring **23** and the N-type conductive layer, and between the gate wiring **24** and the gate electrode **18**.

Furthermore, a drain electrode **19** is formed on the second major surface of the N-type SiC substrate **2**. Thus, the power MOSFET **20** can be completed.

As described above, also in the method for manufacturing the power MOSFET **20** according to this embodiment, after forming a polysilicon layer **36** in contact with the P-type contact region **13** of the 4H—SiC structure, P-type impurity is ion-implanted to form a damage region **37**. Furthermore, heat treatment is performed to form a recrystallized region **5** including 3C—SiC. Thus, a low resistance contact can be realized between the P-type conductive layer **16** and the P-type contact region **13**.

Furthermore, in process after FIG. 6A for forming a gate oxide film **14** on the first major surface of the N-type SiC layer **3**, the process can be performed at a temperature of 1000° C. or less as a treatment at the highest temperature being the heat treatment for recrystallizing the damage region **37** to form 3C—SiC. Thus, for instance, no degradation is caused at the interface of the gate oxide film **14** and the P-type base region **11**. Hence, the variation of threshold voltage V_{TH} and the occurrence of leakage current can be prevented. That is, the method for manufacturing a semiconductor device according to this embodiment can also be easily performed, and is suitable to manufacture the power MOSFET **20**, for instance.

In the power MOSFET **20** according to this embodiment, the recrystallized region **5** is formed only in the surface portion of the P-type contact region **13**. However, it is also possible to use a structure in which the recrystallized region **5** is formed also in the surface of the N-type source region **12**.

For instance, the polysilicon layer **36** formed in FIG. 6C is formed as a conductive polysilicon layer doped with N-type impurity. Furthermore, the ion implantation of N-type impurity shown in FIG. 7A can be selectively performed to form a damage layer in the surface of the N-type source region **12**. Thus, the recrystallized region **5** can be formed also in the surface of the N-type source region **12**.

(Third Embodiment)

FIG. 9 is a schematic view showing a cross section of a semiconductor device according to a third embodiment. The power MOSFET **30** according to this embodiment is different from the power MOSFET **20** according to the second embodiment in having a PMOS structure formed in a P-type SiC

layer **53**. In the description of this embodiment, it is assumed that the first conductivity type is P-type and the second conductivity type is N-type.

As shown in FIG. **9**, the power MOSFET **30** includes a P-type SiC layer **53** having a hexagonal crystal structure, an N-type base region **54** as a first semiconductor region, a P-type source region **55** as a second semiconductor region, and an N-type contact region **56** as a third semiconductor region. The N-type base region **54** is provided in the first major surface, i.e., the surface of the P-type SiC layer **53**. The P-type source region **55** is selectively provided in the surface of the N-type base region **54**. The N-type contact region **56** is selectively provided in the surface of the N-type base region adjacent to the P-type source region **55**.

A P-type conductive layer **58** as a first conductive layer and an N-type conductive layer **57** as a second conductive layer are provided on the P-type source region **55** and the N-type contact region **56**, respectively. A recrystallized region **5** including 3C—SiC is formed in the portion of the P-type source region **55** in contact with the P-type conductive layer **58**.

In the power MOSFET **30** according to this embodiment, 3C—SiC included in the recrystallized region **5** is in contact with the P-type conductive layer **58**. Thus, also in the power MOSFET **30** according to this embodiment, the contact resistance between the P-type source region **55** and the P-type conductive layer **58** can be reduced. Furthermore, the recrystallized region **5** can also be formed in the surface of the N-type contact region **56**.

(Fourth Embodiment)

FIG. **10** is a schematic view showing a cross section of a semiconductor device according to a fourth embodiment. The semiconductor device according to this embodiment is an IGBT **40** (insulated gate bipolar transistor) made of SiC.

As shown in FIG. **10**, the IGBT **40** includes an N-type SiC layer **3** having a hexagonal crystal structure, a P-type base region **11**, an N-type emitter region **63**, and a P-type contact region **13**. The N-type SiC layer **3** is formed on the first major surface of a P-type SiC substrate **61** made of 4H—SiC. The P-type base region **11** is provided in the first major surface, i.e., the surface of the N-type SiC layer **3**. The N-type emitter region **63** is selectively provided in the surface of the P-type base region **11**. The P-type contact region **13** is selectively provided in the surface of the P-type base region **11** adjacent to the N-type emitter region **63**.

A gate electrode **18** is provided above the P-type base region **11** via a gate oxide film **14**. A collector electrode **62** is provided on the second major surface of the P-type SiC substrate **61**.

On the other hand, an N-type conductive layer **16** and a P-type conductive layer **17** are provided on the surface of the N-type emitter region **63** and on the P-type contact region **13**, respectively. Furthermore, an emitter wiring **64** is provided on the N-type conductive layer **16** and the P-type conductive layer **17**. A recrystallized region **5** including 3C—SiC is formed in the surface portion of the P-type contact region **13** in contact with the P-type conductive layer **17**.

Also in the structure of the IGBT **40** according to this embodiment, the contact resistance between the conductive layer and the N-type emitter region **63** made of 4H—SiC and

between the conductive layer and the P-type contact region **13** made of 4H—SiC is reduced by forming an N-type conductive layer **16** and a P-type conductive layer **17** in contact with the N-type emitter region **63** and the P-type contact region **13**, respectively. Furthermore, the IGBT **40** is configured so that a recrystallized region **5** is formed in the surface portion of the P-type contact region **13**. Thus, the recrystallized region **5** including 3C—SiC is brought into contact with the P-type conductive layer **17** to reduce the contact resistance.

The invention has been described above with reference to the first to fourth embodiments according to the invention. However, the invention is not limited to these embodiments. For instance, within the spirit of the invention, those skilled in the art may be able to conceive various modifications such as changes in design and material based on the technology level at the time of filing this application. Such modifications are also encompassed within the scope of the invention.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modification as would fall within the scope and spirit of the inventions.

What is claimed is:

1. A semiconductor device comprising:

a SiC layer of a first conductivity type having a hexagonal crystal structure;

a first SiC region of a second conductivity type selectively provided in the SiC layer, the first SiC region having a hexagonal crystal structure;

a second SiC region of the second conductivity type selectively provided in the first SiC region, the second SiC region having a cubic crystal structure; and

a conductive layer of the second conductivity type provided on the second SiC region, and being in contact with the second SiC region, wherein the first and second conductivity types are opposite conductivity types.

2. The device according to claim 1, wherein the conductive layer comprises polysilicon.

3. The device according to claim 1, wherein the conductive layer is in contact with both the SiC layer and the first SiC region.

4. The device according to claim 3, wherein a contact resistance between the conductive layer and the second SiC region is lower than a contact resistance between the conductive layer and the first SiC region.

5. The device according to claim 1, wherein the first SiC region includes aluminum as an impurity.

6. The device according to claim 5, wherein the second SiC region includes aluminum and boron as an impurity.

7. The device according to claim 1, further comprising: an electrode electrically connected to the conductive layer.

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